The early clinical and angiographic outcome of sequential coronary artery bypass grafting with the off-pump technique

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Objective: The emergence of the off-pump coronary artery bypass technique has made surgeons consider combining it with other techniques developed and learned with conventional coronary artery bypass grafting with cardiopulmonary bypass. One of these techniques is the construction of a sequential graft to bypass more than one coronary vessel. The purpose of this study is to review the outcome of combining sequential coronary artery bypass grafting with off-pump techniques.

Methods: We retrospectively reviewed the records of 45 consecutive patients who underwent isolated coronary bypass surgery with off-pump and sequential grafting techniques at Harefield Hospital (Harefield, UK) between July 1999 and December 2000. The registry database, medical notes and charts were studied for preoperative and postoperative data of the patients. Ten patients consented and underwent early postoperative angiography to check the quality of the grafts and anastomoses.

Results: There were no deaths among the study patients. Morbidity consisted of atrial fibrillation in 6 patients (13.3%), leg wound infection in 2 patients (4.4%), and pleural effusion in 1 patient (2.2%). Early angiography of the 10 consenting patients revealed 10 patent sequential grafts (100%) with 20 satisfactory end-to-side and side-to-side anastomoses (100%).

Conclusion: The combination of sequential grafting and off-pump techniques is feasible, is safe, and provides good early clinical and angiographic outcomes.

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Arterial or venous sequential graft technique in coronary artery bypass grafting (CABG) emerged in the 1970s, and the evidence of efficacy and satisfactory patency published in the 1980s encouraged its wider use.[1,2] This technique became increasingly popular in the 1990s, when it was used and studied for both arterial and venous grafts with promising results.[3-7] At the same time, there has been an accumulating body of evidence suggesting potential advantages of off-pump CABG rather than conventional CABG with the use of cardiopulmonary bypass.[8,9] Combining sequential grafting and off-pump CABG techniques could help increase the number of distal coronary anastomoses with limited number of grafts and avoid multiple proximal aortic anastomoses. However, there is still some concern regarding the quality of anastomoses and patency of grafts when the techniques are combined. The aim of this study was to demonstrate the early clinical and angiographic outcomes of such combination.

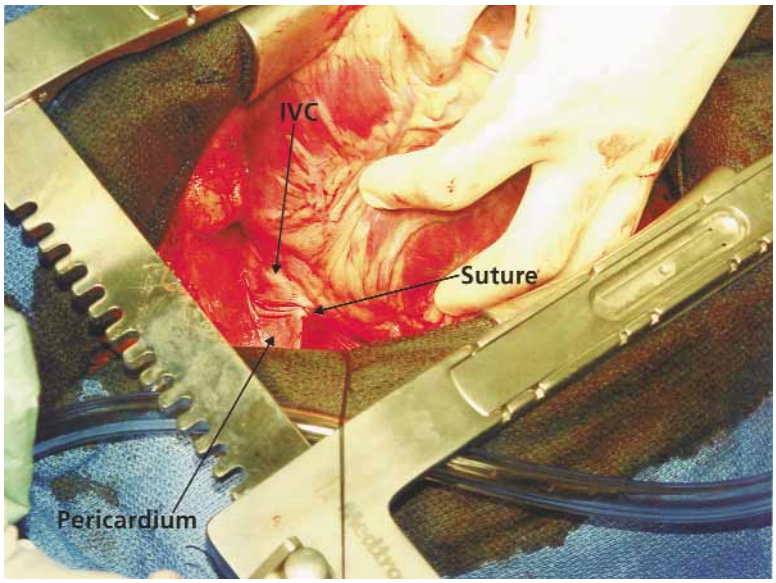

Figure 1. One deep pericardial retraction suture is placed at posterior fibrous pericardium close and medial to most proximal part of inferior vena cava *(IVC).*

TABLE 1. Preoperative characteristics

Variable	No. (N = 45)	%
Female	6	13.3
Diabetes mellitus (type 2 or type 1)	16	35.5
Hypertension	15	33.3
Unstable angina	15	33.3
Hypercholesterolemia	24	53.3
Triple-vessel disease	45	100
Left main stem stenosis >50%	4	8.9
Ejection fraction		
>50%	20	44.4
>30%-50%	18	40
0%-30%	7	15.5
Chronic obstructive airway disease	2	4.44
Previous transient ischemic attack or cerebrovascular accident	2	4.44
Urgent or emergency operation	5	11.1

Material and Methods

Data Collection

Since our conversion to nonselective off-pump CABG for multivessel coronary artery disease in July 1999, we have performed sequential grafting in 45 out of 290 cases (15.51%) with the off-pump CABG technique. The records of these 45 consecutive patients who underwent isolated CABG (all performed by a single surgeon, M.A.) at Harefield Hospital (Harefield, UK) between July 1999 and December 2000 were reviewed retrospectively. Registry database, medical notes, and charts were studied for preoperative and postoperative data of the patients. The average age at operation was 65.67 ± 11.16 years, with a range of 32 to 88 years. The rest of the preoperative characteristics of the patients are shown in Table 1.

Angiography

After our early satisfactory clinical experience with the first consecutive 35 patients, we decided to approach the next 10 patients about angiographic examination. All these patients consented to and underwent early postoperative angiography. Angiography was performed before discharge, at the earliest on the fourth postoperative day, and looked at the quality of the anastomoses and the patency of the grafts. Institutional approval was obtained for the study. Insufficient flow or hypoperfusion in the immediate postoperative period can occur in any arterial or venous bypass graft and is most often related to technical errors in constructing the distal anastomoses or attaching the graft to the epicardium.[10] All the angiograms were performed and commented on by a single cardiologist (M.B.).

Operative Technique

Anesthesia. Anesthesia was induced with propofol at 1 to 2 mg/kg, pancuronium at 0.1 mg/kg, and fentanyl at 8 to 15 μg/kg and was maintained by inhalation of an air-oxygen mixture with propofol at 2 to 3 mg/(kg · h). Anticoagulation was achieved with heparin at 150 U/kg given after completion of harvesting the internal thoracic artery (ITA) grafts. The activated clotting time was always maintained at greater than 250 seconds. Transesophageal echocardiography was used for additional monitoring as required.

Low cervical or high thoracic epidural analgesia was used for all patients. The epidural catheter was inserted at least 6 hours before the operation and maintained for 72 hours after the operation. In addition to its effect in postoperative analgesia, we believe that thoracic epidural analgesia plays a role in early graft patency, possibly by inducing sympatholysis, which seems to improve myocardial blood flow during the early postoperative period.[11-16]

Normothermia was maintained by using warm intravenous fluids, a heating mattress, and a humidified airway and by maintain-

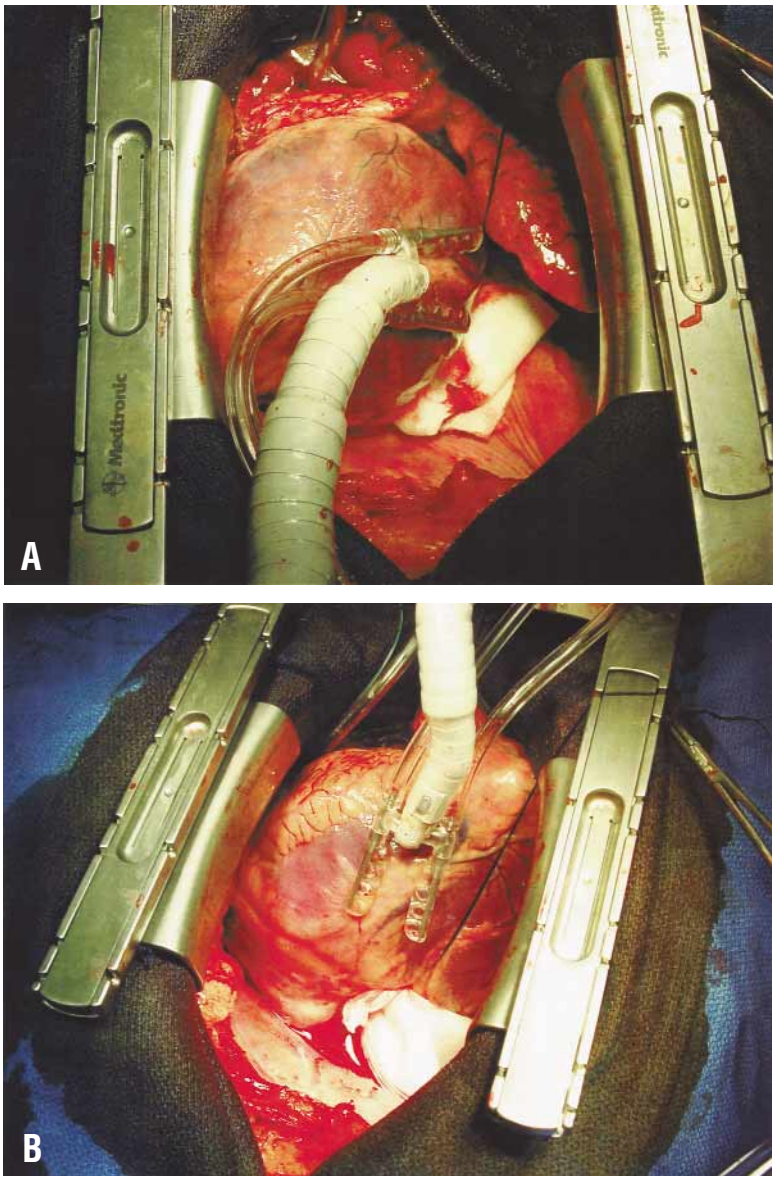

Figure 2. Suture acts as lever that helps surgeon manipulate and rotate heart to vertical and lateral positions with Octopus. Wet gauze swab is placed between suture and posterior surface of heart to avoid tearing myocardium or compressing posterior coronary vessels.

ing a warm operating theater. A standby perfusionist with primed bypass circuit was available for all cases.

Surgical technique

Approach and exposure. A standard midline sternotomy was used to expose the heart. The pericardium was opened with an inverted T-shaped incision after the harvest of the ITAs. The right pleural space was opened to create a space for the vertically placed heart, to minimize hemodynamic compromise. This was followed by evaluation of coronary artery status.

Harvesting of conduits. Left ITA (LITA) was harvested as a wide pedicle including artery, vein, muscle, fascia, and adipose tissue. Gentle dissection was begun at the distal end of the artery to ensure adequate length in case of injury. The ITA was sprayed with diluted papaverine solution (50 mg/20 mL isotonic sodium chloride solution), and after adequate flow was ensured a bulldog clamp was applied to control bleeding from the distal end. The same technique was applied in harvesting the right ITA (RITA).

The left radial artery was used preferentially, regardless of the hand dominance, because this allows simultaneous harvesting of the LITA. It is our practice to use a flushing solution that consists of 50 mg phenoxybenzamine, 20 mL blood, and 2000 units of heparin. This mixture was used for all the study patients. Phenoxybenzamine is a long-acting, irreversible α-blocker that

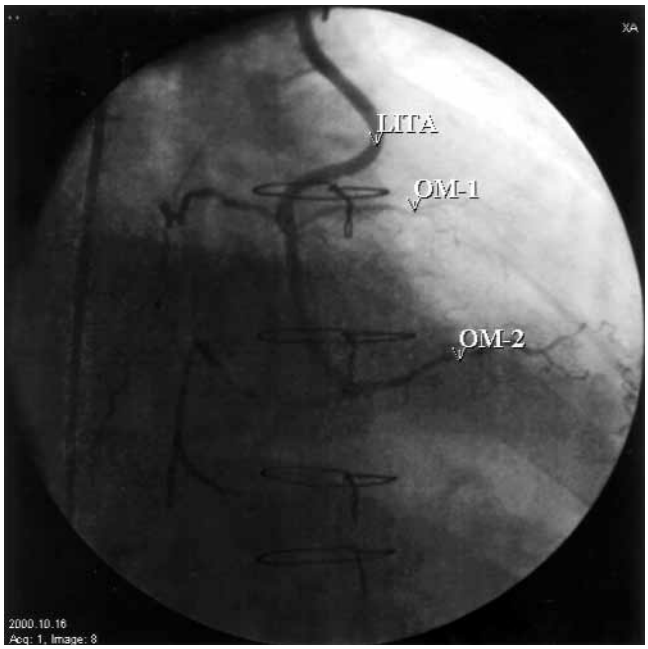

Figure 3. Most sequential grafts (64.4%) involved circumflex territory vessels (circumflex coronary artery *[Cx],* first obtuse marginal artery *[OM-1],* second obtuse marginal artery [*OM-2*]) either fully or partially.

TABLE 2. Analysis of the anastomosis sequences of all the sequential grafts

	Anastomosis sequence			
Conduit	**Side-to-side**	**End-to-side**	**No.**	**%**
LITA	LAD	Diag	12	26.6
	OM1	OM2	3	6.6
	Cx	OM1	2	4.4
RITA	Cx	OM1	1	2.2
LRA	Cx	PDA	7	15.5
	Cx	LV	5	11.1
	Cx	OM1	2	4.4
	OM1	OM2	2	4.4
	PDA	LV	4	8.8
SVG	Diag	Cx	2	4.4
	Cx	PDA	2	4.4
	OM1	PDA	2	4.4
	OM1	LV	1	2.2

LAD, Left anterior descending coronary artery; *Diag,* diagonal artery; *OM1,* first obtuse marginal artery; *OM2,* second obtuse marginal artery; *Cx,* circumflex coronary artery; *LRA,* left radial artery; *PDA,* posterior descending coronary artery; *LV,* left ventricular branch of right coronary artery; *SVG,* saphenous vein graft.

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could potentially prevent radial artery spasm for a relatively long period.[17]

Cardiac stabilization and manipulation. The heart was stabilized with a suction-irrigation tissue stabilization system (Octopus 3; Medtronic Inc, Minneapolis, Minn). One deep pericardial retraction suture was placed at the posterior fibrous pericardium close and medial to the most proximal part of the inferior vena cava (Figure 1). This suture is a personal modification (by M.A.) of previously described deep pericardial retraction sutures. It acts as a lever that helps the surgeon manipulate and rotate the heart to vertical and lateral positions along with the Octopus. A wet gauze swab was placed between the suture and the posterior surface of the heart to avoid tearing of the myocardium or compression of the posterior coronary vessels (Figure 2).

Sequential grafting strategy. Sequential grafting was performed to increase the number of distal coronary anastomoses with a limited number of grafts. It was also indicated to minimize the manipulation of the aorta in elderly patients and patients with heavily calcified aortas. Essentially, the main criteria for sequential grafting were needs to increase the number of arterial grafts or avoid manipulation of diseased aortas, as assessed by preoperative echocardiography or digital palpation. When total arterial revascularization was indicated (patients younger than 65 years) and the use of bilateral ITA grafts was contraindicated, sequential grafting was preferentially used. The proximal side-to-side anastomosis was performed first, followed by the distal end-to-side anastomosis. Indeed, when the distal end of the graft remains free (not yet sutured), this provides a better control of the graft and the proximal anastomosis. It allows each bite on the coronary and graft arteriotomy sites to be visualized and controlled. Furthermore, we believe that better control of the sutures is provided when the parachute technique is used. This would be somehow more difficult to achieve if the distal (end-to-side) anastomosis were constructed first. There was no difference in the surgical technique of constructing the side-to-side anastomosis with venous and arterial grafts. The quality was satisfactory for all the conduits used as sequential grafts. The size of the coronary arteriotomy was dictated by the caliber of the grafts.

Results

Conduits and Targets

During the study period we performed sequential grafting on 45 patients with the off-pump CABG technique. The total number of distal anastomoses was 166, with an average of 3.69 ± 0.47 per patient. Fourteen patients (31.1%) had three distal anastomoses, whereas 31 patients (68.9%) had four distal anastomoses. Each patient had one sequential graft with two distal anastomoses. The details of the side-to-side and the end-to-side anastomoses are presented in Table 2.

The most common sequential graft (26.6%) was the LITA for the left anterior descending coronary artery (side-to-side) and the diagonal artery (end-to-side). The second most common sequential graft (15.5%) was the radial artery for the circumflex coronary artery (side-to-side) and the posterior descending coronary artery (end-to-side). Twenty-nine sequential grafts (64.4%) involved the circumflex territory vessels (circumflex coronary artery, first obtuse marginal artery, second obtuse marginal artery) either fully or partially (Figure 3).

Thirty-eight (84.5%) sequential grafts were arterial (LITA, RITA, and left radial artery), whereas there were only 7 sequential saphenous venous grafts (15.5%). This represents our policy of routine total arterial revascularization in patients younger than 60 years and partial arterial revascularization (2 arterial grafts) in patients between 60 and 70 years old.[18]

All the LITA grafts were pedicled grafts. Eight (40%) of the left radial artery grafts and the only RITA graft were Y-grafts off the LITA grafts. The details of the proximal ends are presented in Table 3.

TABLE 3. Analysis of the proximal anastomoses of all the sequential grafts

		Free		
Proximal end conduit	Pedicled	Off aorta	Off LITA	Total
LITA	17	0	0	17
RITA	0	0	1	1
LRA	0	12	8	20
SVG	0	7	0	7
Total	17	19	9	45

LRA, Left radial artery; *SVG,* saphenous vein graft.

Angiography

Angiography was performed on 10 (22.2%) of the 45 patients before discharge at the earliest on the fourth postoperative day. All the 10 sequential grafts were patent, as confirmed by two orthogonal views, which included 20 anastomoses (10 side-to-side anastomoses and 10 end-to-side anastomoses) that were all satisfactory in terms of technique, patency, and flow. All the grafts were of acceptable caliber, and no string effect was noted. The details of the sequential grafts studied by angiography are presented in Table 4.

TABLE 4. Analysis of the sequential grafts studied by angiography

	Anastomosis sequence		
Conduit	Side-to-side	End-to-end	No.
LITA	LAD	Diag	1
	OM1	OM2	2
RITA	Cx	OM1	1
LRA	Cx	PDA	1
	Cx	OM1	1
	PDA	LV	2
SVG	Cx	PDA	1
	OM1	PDA	1
Total			10

LAD, Left anterior descending coronary artery; *Diag,* diagonal artery; *OM1,* first obtuse marginal artery; *OM2,* second obtuse marginal artery; *Cx,* circumflex coronary artery; *LRA,* left radial artery; *PDA,* posterior descending coronary artery; *LV,* left ventricular branch of right coronary artery; *SVG,* saphenous vein graft.

Postoperative Course

There were no deaths among the study patients within 30 days after the operation. The average stay in the intensive therapy unit was 15.3 ± 2.74 hours. The average hospital stay was 5.53 ± 1.43 days. The average duration of mechanical ventilation was 7.46 ± 2.23 hours. None of the patients had low cardiac output, perioperative myocardial infarction, or sternal wound infection. The postoperative complications that occurred included atrial fibrillation in 6 patients (13.3%), leg wound infection in 2 patients (4.4%), and pleural effusion that did not require aspiration or drainage in 1 patient (2.2%). None of the patients had neurologic, renal or pulmonary complications.

Discussion

This retrospective study shows that combining sequential grafting and off-pump CABG techniques is feasible, is safe, and provides good early clinical and angiographic outcomes. CABG that ensures complete myocardial revascularization is the most effective treatment for patients with symptomatic triple-vessel coronary artery disease.[18] Sequential grafting helps increase the number of distal coronary anastomoses with a limited number of grafts. This is particularly important when there is lack of suitable conduits because of poor quality, inadequate length, or relative contraindication (eg, contraindication of the use of bilateral ITAs in patients with diabetes). In addition, combining this technique with the off-pump CABG technique provides more advantages by making the approach of complete myocardial revascularization more achievable with avoidance of manipulation and multiple side clamping of the aorta, particularly for elderly patients and patients with heavily calcified aortas. Furthermore, performing sequential grafts with the off-pump CABG technique adds to the ease of estimating the distance between the side-to-side and end-to-side anastomoses while the heart is full and beating.

The combination of sequential grafting and off-pump CABG techniques can be challenging, however, particularly when approaching the posterior and lateral myocardial territories. This requires lifting, vertical placement, and rightward rotation of the heart, and maintaining this position for long may lead to hemodynamic compromise. By using the deep pericardial retraction suture, however, we have found it easy to approach these sites, as reflected by the fact that a significant number of the sequential grafts (64.4%) involved the circumflex territory vessels (circumflex coronary artery, first obtuse marginal artery, second obtuse marginal artery) either partially or fully.

During the last 2 years we have been using the off-pump CABG technique nonselectively for all patients. At the same time we have adopted the policy of routine total or partial arterial revascularization, which explains why most of the sequential grafts we performed were arterial.

The combination of these two challenging techniques might raise concerns about the quality of the performed anastomoses. However, we believe that use of the described method of approach and stabilization makes sequential anastomoses technically feasible with satisfactory outcome. This is reflected by the excellent early angiographic results, which proved complete patency of the sequential grafts and efficient flow through them. Furthermore, they ruled out any technical errors in performing the side-to-side and end-to-side anastomoses. Sequential grafting and off-pump CABG are thus two established techniques in coronary surgery that can be safely combined to provide good early clinical and angiographic outcomes.

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